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Russian Translation

Temperature Measurement by Radiation Under High Pressure and Certain Optical Phenomena in Gases Under These Conditions

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Thermocouples or much more rarely, resistance thermometers are used to measure temperatures in high pressure apparatus. In the majority of cases, the temperature transmitters are placed deep within the apparatus, it being considered that the temperature of the vessel and its internal cavity are identical.

However, in those cases when any processes accompanied by a thermal effect (chemical reactions, polymorphic transformations, etc.) occur in the apparatus, the temperature transmitters must be placed in the high-pressure zone itself. This same condition, understandably, is necessary if heating is applied within the high-pressure vessel itself. (Internal heating is used to obtain temperatures higher than 450 - 500° C since preheating the whole apparatus on the outside tends to weaken its strength).

Temperature transmitters placed within the apparatus are thus subjected to the effect of the ambient medium. This effect will be manifest in a hydrostatic multilateral compression, the possible diffusion of the compressed medium into the transmitter material, chemical interaction etc. The influence of the pressure at high temperatures will be especially strong. All these phenomena can distort the transmitter signals more-or-less strongly and, hence, lead to false measurements. The application of contact transmitters using aggressive substances is completely inadmissible.

Radiation pyrometers are contactless indicators, consequently, they are most appropriate for temperature measurements at high pressures.

1. Construction of the pyrometer

As is known (Stefan-Boltzmann law), the total radiation of an absolutely black body is proportional to the fourth power of the absolute temperature. Hence, even significant errors in estimating the radiation intensity would not lead to large errors in the magnitude of the temperature. Analysis of curves showing Planck's law in λ (wavelength), I (radiation intensity) coordinates shows that the radiation intensity grows particularly strongly in the comparatively shortwave region ($< 4\mu$). Consequently, using only part of the radiation spectrum with the definite wavelength rather than all of it, the radiation intensity can be obtained as increasing in proportion to the 10-12th power and even higher of the temperature. This is attained by using appropriate light-filters [1,2] and it permits the temperature to be measured exactly by a comparatively rough instrument. The radiation methods of measuring the temperature are three: optic, photo-electric and radiation [1,2]. The optic method is a subjective one and suitable to measure temperatures starting with 800° and higher. The photo-electric method is objective and has high sensitivity but special photocells are required to measure temperatures below 700° C. The radiation method is suitable to measure any temperature but its sensitivity is comparatively low [3].

Since temperatures starting with $350\text{-}400^{\circ}$ C were required for our investigations, the photoelectric method using photocells sensitive to infra-red rays was selected. Photocells with external effect [4-6] are the most stable under variation of external conditions (temperature, humidity, etc.) of the flow of radiation and in time. Of these photocells only the cesium-oxide is sensitive to infra-red radiation and then, too, to the very near - its red boundary is about 1.1μ; the sensitivity is low:

30 - 40 $^{\mu a}$/lumen.

Using this photocell, even after amplifying the primary photocurrent by several thousand times, did not give a positive result at temperatures below 700° C in our apparatus. Modern photo-multipliers of the FEU-17 or FEU-19 type (antimony-cesium) have sections of the characteristic with low sensitivity in the very near infra-red range (less than 0.9 μ) [7]. However, it could be hoped that because of the enormous photo-multiplier gain, it will react at the temperatures we require. An attempt to use the photo-multiplier also was not crowned with success. Consequently, photo-conductors had to be selected as transmitter (a photocell with an external photo-effect) which are very unstable and capricious in operation but which have high sensitivity and certain of them in precisely the infra red range [4-6]. Thalofide photo conductors with a sensitivity of 6000 $^{\mu a}$/lumen and a red boundary of 1.2 μ are the most widespread of these latter. Such a red boundary was not long enough on the basis of the previous experiments. Recently, photo conductors have been prepared on a lead sulfide, selenium and lead telluride base which have a much more remote red boundary than the other photocells and a high sensitivity and they are widely used [8-13].

Zinc sulfide photo-conductors for the infra-red band, mark FS-A1 or FS-A4 [14,15] have been used by our industry.

The FS-A1 parameters are the following [16]: Sensitivity, 5000-8000 $\frac{\mu a}{\text{lumen}}$, red boundary 3.1 μ , maximum sensitivity at the 2.1 μ wavelength.

Consequently, the FS-A1 was selected as the transmitter for the photoelectric pyrometer. Photo-current amplification was required to measure temperatures starting with 300° C . As is known, d.c. amplifiers are complex, unstable with time, and it is difficult to control noise therein [17]. Moreover, the instability of the photo-conductor itself makes it unsuitable for connection to d.c. amplifiers. Consequently, an a.c. amplifier was developed according to the circuit of figure 1.*

In order to creat an alternating signal, the light stream is interrupted by a perforated disc put on the rotor of an electric motor. The electric motor rotated at 1400 rpm . The disc diameter and the quantity of orifices were such that the light interruption frequency was about 840 cps .

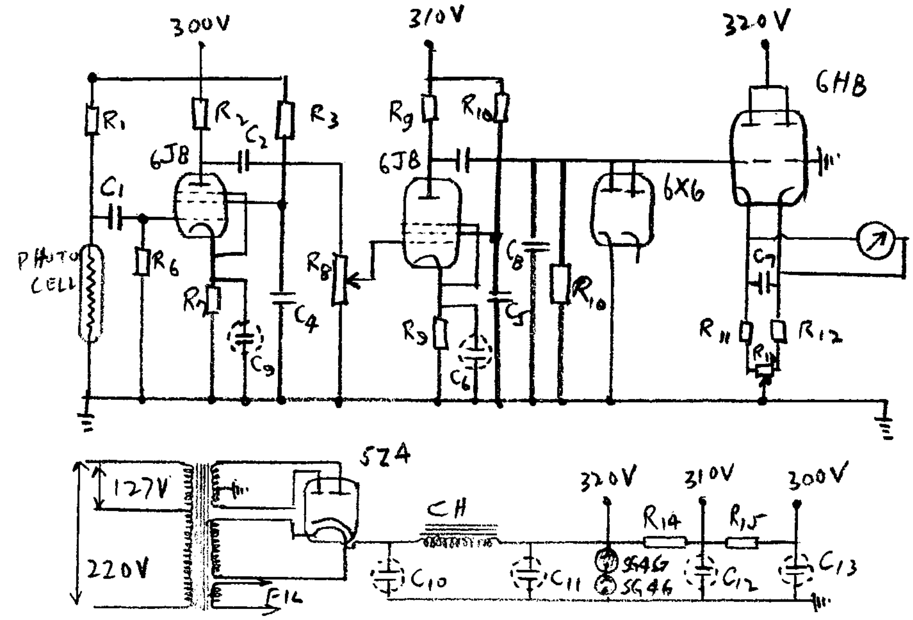

Figure 1. Amplifier circuit

R_1 = 2 megohms; R_2 = 18 K; R_3 = 36K; R_4 = 220 K; R_5 = 910K; R_6 = 300 K; R_7 = 100 ohms; R_8 = 1 meg; R_9 = 750 ohms; R_{10} = 310 K; R_{11} = 3.9 K; R_{12} = 3.6 K; R_{13} = 0.5 K; R_{14} = 3.3 K; R_{15} = 3 K; C_1 = 0.01 μf; C_2 = 0.015 μf; C_3 = 0.015 μf; C_4 = 0.5 μf; C_5 = 0.5 μf; C_6 = 2.5 μf; C_7 = 0.25 μf; C_8 = 2200 μμf; C_9 = 25 μf; C_{10} = 20 μf; C_{11} = 20 μf; C_{12} = 10 μf; C_{13} = 10 μf .

II. Construction of the apparatus

Apparently just Basset used the radiation method of determining the temperature in high-pressure apparatus. He used only an optical method [18,19]. The optical system of his installation is very simple: Thick, glass apertures withstanding the high pressure were ground down to the steel walls of the

* Engineer N. M. Anosov constructed the amplifier.

vessel (sealing by the Poulter method [20]). It is understood that the windows were placed in the unheated parts of the apparatus so that the heated zone on which the optical pyrometer was sighted could be seen through them. There are many obscurities in the Basset works; thus, for example, there is not one number on the degrees measured by this method in all his papers on the optical method of measuring the temperature published in 1932 but only the useful temperature ranges are mentioned. Naturally, compressing a medium should exert some kind of effect on the radiation penetrating therein; Basset does not give any numbers on this but only says that such phenomena were 'taken into account' [19]. In one of the works [21] where the temperature was established by an optical method, the temperature limits 500 - 1200° C are stated which is inconceivable since the optical pyrometer has a lower limit of 750 - 800° [1].

All this raised doubts as to the validity of the Basset work and it was decided to verify them. The high-pressure cylinder itself is described in detail in one of the previous works [22]; additions were introduced in it for this work which would permit the radiation to be investigated. The cylinder diagram is given on figure 2, in principle. The diameter of the optical glass window is 15 mm, the thickness is 10 mm. The window was ground down into the obturator faceplate to two Newton rings; the diameter of the obturator orifice is 8 mm. The length of the channel from the window to

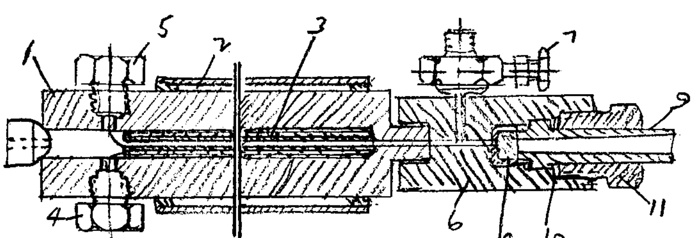

Figure 2. Cylinder diagram
1 - Cylinder frame; 2- cooling water jacket;
3 - tubular furnace with heat insulator;
4 - current supplying electric input;
5 - special electric input for the thermocouple [23]; 6 - shaped connector; 7 - release valve; 8 - high-pressure glass window;
9 - obturator; 10 - compression ring;
11 - collar

the bottom of the cylinder is 85 mm , its diameter is 3 mm . A steel disc clamped in place by a special rod was inserted in the furnace heating tube around the thermocouple junction. The distance between the disc and the bottom of the cylinder is 205 mm . The thermocouple was of chromel-alumel; According to Birch [24], this thermocouple has a negligible thermal emf behavior with pressure. The general view of the installation is given on figure 3 .

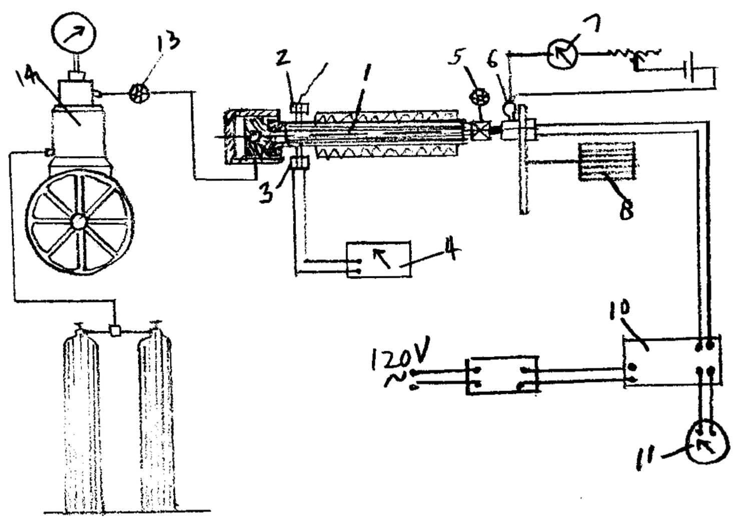

Figure 3. Installation diagram
1 - Cylinder with furnace and shaped connector; 2 - current supplying electric input; 3 - electric input for the thermocouple; 4 - pyrometer; 5 - cleansing valve; 6 - calibrating tube; 7 - milliammeter; 8 - electric motor with disc; 9 - photo conductor; 10 - amplifier; 11 - galvanometer; 12 - EPA-15 voltage stabilizer; 13 - release valve; 14 - compressor; 15 - gas cylinders.

The pressure was created by a single-stage gas compressor of very high pressure [25]. Because of the high instability of the photo conductor, its sensitivity was checked periodically by the calibrating tube supplied by a current of strictly constant magnitude controlled by the milliammeter 7 (fig. 3). The reading on the instrument 11 at the output was established at the very same division, for such a tube incandescence, by regulating the amplifier. Hence, the general sensitivity of the photocell pyrometer was invariant in all the experiments. A brass blind was superimposed (not shown in the diagram) at the time of calibrating the flow of radiation from the cylinder.

III. Experimental results

Inasmuch as the radiation passes through an optical glass window, it will have a red boundary around 2.2 μ [5].

Since the FS-1 photoconductor has a drop in the sensitivity for wavelengths shorter than 0.7 μ [16], the spectrum perceptible to the optical pyrometer will be approximately 0.75 - 2.1 μ .

It can be assumed that the radiation will be proportional to the seven-eighths power of the temperature for such a wavelength range [1,2]. It was proposed to use gases: nitrogen, hydrogen and their mixtures, as the compressible medium. As is known [26], such gases do not have absorption in the above-mentioned range under usual pressures. The weak absorption bands manifest in these substances at high pressures lie in the more distant range than 2.2 μ and, consequently, cannot be confused [27-32].

Water as well as oil present in the medium have absorption bands in this region [33] but their quantity is so small that they can exert no perceptible influence on the radiation. A comparison was made first of the readings of the thermocouple and of the instrument at the output (11 of fig. 3) of the photo-electric pyrometer at 1 atm. of nitrogen. Required as an instrument in the first series of experiments was a 3 V voltmeter with a 60 division scale and an internal resistance of $R_{in} = 3$ K . All the results referring to the readings on the photoelectric pyrometer were denoted by FEP (table 1).

Table 1 . P = 1 kg/cm^2 . Medium - Nitrogen

T, $^\circ$ C	0°	300°	350°	400°	450°
FEP, in scale divisions	0	0.8	4.5	11.2	25.0

Nitrogen was pumped to a pressure of 700 $^{kg}/cm^2$ in the cylinder and then the furnace was connected (table 2).

Table 2. P = 700 $^{kg}/cm^2$. Medium - Nitrogen

T, $^{\circ}$ C by thermocouple	0°	300°	350°	400°
FEP , in scale divisions	0	0.3	1.2	5.8 at the start then became 3.0

Keeping the temperature at 400° C according to the thermocouple, the pressure was varied; the results are shown in table 3 .

Table 3. T = 400° C , by thermocouple. Medium - Nitrogen

P , $^{kg}/cm^2$	700	500	350	200	1
FEP , in scale divisions	3.0	4.0	4.2	2.0	11.0

As the gas is released through the valve in front of the FEP window, (see 5, fig. 3), the readings instantaneously drop to zero. The readings are reestablished when the valve is overlapped. As the gas is released through the valve by the compressor (see 13, fig. 3), the FEP readings did not change at first but then dropped to a specific value (but not to zero). When the gas was released suddenly through this valve, the readings on the FEP oscillated widely for the first 2-3 sec. after the valve was opened and then the FEP readings again dropped to a very small value.

An experiment was made in the reverse sequence. The furnace within the cylinder was heated to 400° C and then the pressure was increased as the temperature was kept constant (table 4).

Table 4. T = 400° C , by thermocouple. Medium - Nitrogen

P , $^{kg}/cm^2$	1	80	200	1
FEP , in scale divisions	11.0	6.5	2.4	10.8

The pressure from 1 - 80 $^{kg}/cm^2$ was attained by connecting the cylinder to the gas cylinder briefly. As the pressure increased from 80 to 200 $^{kg}/cm^2$ the arrow on the instrument at the FEP output recorded each stroke of the compressor piston exactly, falling and rising with the piston cycle. After

200 $^{kg}/cm^2$ had been attained, the absolute value of the FEP readings was very small and the oscillations of the pointer became so small that it was impossible to follow them.

Because of the above, it was resolved to study similar phenomena visually. The photo-electric pyrometer was removed and the usual periscope, which would permit the furnace interior beyond the high-pressure safe to be observed, was fastened to the obturator outlet (see 9, fig. 2). The furnace was heated to 700° C and a small circle of red color of definite brightness was seen in the periscope; then nitrogen was pumped into the cylinder while the furnace was maintained at 700° C according to the thermocouple. When the cylinder was connected briefly to the gas cylinder (80 $^{kg}/cm^2$) the brightness first dropped to zero and then became approximately one-half the original. Further visual observations confirmed the data obtained using the FEP completely.

The small red circle dimmed then flashed with each stroke of the compressor piston, wherein its brightness became less and less. At 250 $^{kg}/cm^2$, the brightness of the small circle became approximately one-fourth the value at 1 $^{kg}/cm^2$ (subjective estimate). As the gas was released through the valve in front of the high-pressure window, the brightness dropped slowly to zero. This total disappearance of the brightness occurs at all pressures above 100 $^{kg}/cm^2$ if there is a channel. Hence, the results of our experiments diverge completely from the statements of Basset that the temperature measurement is possible by such a method.

It has been shown in our previous work that very intense convection currents arise at high pressures and in the presence of a temperature gradient [22,34]. It is evident that medium will be in a very strong turbulent region in the space between the furnace, where the temperature is high, and

and the window where the temperature is always the same as the room. Moreover, the temperature gradient involves the gradient of the refractive index of the medium in the space between the window and the furnace. Hence, an intensive dispersion and reflection of the radiation must occur in this region. A rod of fused quartz of 2.2 mm diameter was inserted in the channel connecting the furnace and the high-pressure window in order to confirm this assumption. The length of the rod was such (166 mm) that its end entered sufficiently deeply (50 mm) into the hot zone of the furnace. Part of the lateral surface of the rod was made dull (precisely that part which was in the hot zone) and the rest was silver-plated. Its endplates were polished to mirror brilliance. The thermocouple junctions were at approximately 20 mm from the rod endplates. One endplate of this light-conductor closely abutted the center of the high-pressure window (the rod was fastened to the window by a special instrument), the other end was in the furnace. A diagram of the installation with the light-conductor is shown on figure 4.

A comparison of the FEP readings without and with the light-conductor at atmospheric pressure gave the results shown in table 5 .

Hence, a column of air 3 mm in diameter conducted less energy at atmospheric pressure than the same column of quartz with a 2.2 mm diameter (the cross-sectional area of the quartz was almost one-half that of the air). Moroever, the

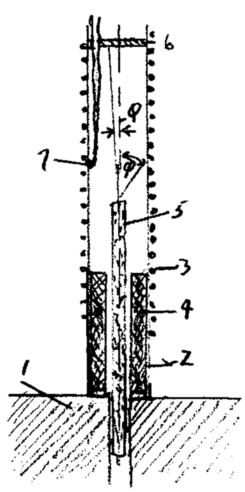

Figure 4. Diagram of furnace with light conductor
1 - Cylinder frame; 2 - heater tube
3 - heater helix; 4 - refractory bushing; 5 - quartz light-conductor;
6 - steel disc; 7 - thermocouple.

absorbing capacity of the quartz is undoubtedly higher than that of the air; the dispersing capacity of crystalline quartz is 7 times greater than air [35]. Consequently, the quartz light-conductor should have conducted a quantity of radiation in tens of times less than would have been conducted in its absence. The explanation of this contradiction will be given below. The experiments carried out with the light-conductor gave results at high pressure shown in table 6.*

Table 5. $P = 1\ ^{kg}/cm^2$. Medium - Air

T, °C, by thermocouple	0°	300°	350°	400°	450°	500°
FEP, in scale divisions without the light conductor	0	0.8	4.5	11.2	25.0	39.3
FEP, in scale divisions with the light conductor	0	3.1	9.3	22.5	42.5	60, off the voltmeter scale

Table 6. a) $T = 400°$ C, by thermocouple. Medium - Nitrogen

P, $^{kg}/cm^2$	1	130	300	600	1000
FEP, in scale divisions	9.5	8.5	10.0	12.4	13.0

b) $T = 450°$ C, by thermocouple

P, $^{kg}/cm^2$	1	130	300	600	1000
FEP, in scale divisions	20.0	20.0	21.6	26.0	28.0

Hence, the FEP readings increases as the pressure increased. As the gas was pumped into the apparatus, the FEP galvanometer did not experience any oscillations due to the compressor operation. No variation occurred in the FEP readings when the gas was released through the valve in front of the high-pressure window.

IV. Discussion of results

As was mentioned above, the phenomena described are explained by the inhomogeneity of the medium with respect to temperature and, therefore, with respect to the density and the refractive index. One of the reasons causing

* A 50 μA microammeter with 100 scale divisions and a 75 K resistor connected in series replaced the voltmeter at the FEP output (see 11, fig. 3) in subsequent experiments.

the attenuation of the radiation is its reflection from the interfaces between separate layers of gas. As was shown in previous works [22,34], the presence of a large temperature gradient at high medium densities leads to the origin of turbulence.

Hence, the space between the heater and the high-pressure window (see fig. 2) will be occupied by a set of gas jets, each of which has a definite boundary, meaning its density, temperature and refractive index. It is understood that the difference in the refractive indices of the separate jets - waviness - is very slight but then their quantity is huge and their location varies continuously in time and space. Hence, the envelopes of such waviness act exactly like reflecting surfaces which continuously change their angle relative to the passing radiation. As is known [35], the Fresnel formula for the energy of reflected light is

$$I_r = I_o \cdot \frac{1}{2}\left[\frac{\sin^2(\varphi - \psi)}{\sin^2(\varphi + \psi)} + \frac{\tan^2(\varphi - \psi)}{\tan^2(\varphi + \psi)}\right]$$

where I_r is the intensity of the reflected ray; I_o is the intensity of the incident ray; φ is the incident angle; ψ is the refractive angle.

As is seen, the energy of the reflected light depends on the incident angle and it varies from a very small quantity at $\varphi = 0^o$ to $I_r = I_o$ at $\varphi = 90^o$. Also, I_r increases as the refractive index increases (in this case, as the difference between the refractive indices of the separate convection currents increases).

Hence, it is clear that a significant part of the radiation energy will be reflected by the convection currents. As the temperature difference increases, the intensity of the turbulence increases, meaning the reflection, which is seen very clearly from a comparison of tables 1 and 2. The growth of the temperature gradient also amplifies another effect which decreases the energy of the transient radiation, which will be discussed below.

As the pressure increases, the intensity of the convection increases in proportion to the density squared [22,34], which increases especially sharply for gases in the 1 - 200-300 $^{kg}/_{cm^2}$ range (by analogy with the compressibility coefficient) as is seen from tables 3 and 4.

The intensity of the convection streams increases many times for forced perturbation of the medium (the natural convection region is replaced by the forced convection region [36]) and, therefore, the reflection of the radiation also increases up to complete absorption of the transient light. This is observed when the gas flows through the valve in front of the high-pressure window and when the gas is pumped by the compressor, when each stroke of the piston gives a jolt perturbing the medium.

All these phenomena vanished completely when the quartz light-conductor was used, which excluded the passage of radiation in the gaseous medium subjected to turbulence. The second reason for the attenuation of the issuing radiation is its molecular scattering by density inhomogeneities. Classical, or Rayleigh scattering, as well as scattering due to the fluctuations in the density of the medium cannot have a large value in the case under consideration because of the smallness of the effect which they cause.

In our experiments without the light-conductor, the temperature gradient in the gas between the heater and the high-pressure window attains several hundred degrees. It is natural that the density of the medium, meaning the refractive index, is variable in this whole space, wherein regions with identical n and ρ will migrate.

It is conceivable that this causes a most strong scattering of the transient radiation, whereupon it will increase as the temperature gradient increases. The turbulent streams which arise at high pressures should be considered as large density inhomogeneities having explicit interfaces besides. Consequently, it is natural that the effects of turbulence and molecular scattering are related by an interdependence and that both increase as the medium density and the temperature gradient increase. This is seen from a comparison of tables 1 and 2 . How large are the inhomogeneities of ρ and n , meaning the scattering, in a medium with a large temperature difference and a low density (where there is no turbulence or it is very small) is shown by our experiments with and without the light-conductor at atmospheric pressure (table 5). It is seen from the results of table 5 that the scattering in air under given conditions is so great that the attenuation of the radiation energy, which occurs when light passes through the quartz rod, is overlapped.

Investigations made in our previous works showed that the temperature at the middle of the furnace was approximately 35° higher than at the ends (see fig. 4) at a pressure of about 1500 $^{kg}/_{cm^2}$ and an average temperature of 600° C (nitrogen is the medium). This difference decreases as the temperature is lowered. As was noted above, no variation occurs in the radiation energy when the medium is perturbed from without (gas release, compressor operation) if the light-conductor is present. Therefore, a turbulent region does not occur (or it is very insignificant) in a compressed gas with the aforementioned temperature gradient. Since neither the gas nor the quartz radiates at the temperatures investigated in the above-mentioned wavelength range [37], all the radiation must be due to the walls of the hot tube 2 and the disc 6 (see fig. 4). As is known [35,38], the intensity of the radiation perceived by any substance depends on its location relative to the radiating body.

If the radiation intensity is denoted by dW , the element of radiator surface by df , the element of receiver surface by df' , the distance between them by R , the incident angle of the rays by φ , then the formula determining the intensity will be

$$dW = \text{const}\,\frac{df\,df'}{R^2}\cos\varphi$$

Hence, the radiation intensity incident on the receiver is proportional to the cosine of the angle of incidence. Moreover, by far not all the energy incident on the endplate of the light-conductor penetrates into the quartz, meaning arrives at the photocell. Only the refracted part of the incident rays is perceived by the photocell, the rest is reflected from the surface of the light-conductor back into the furnace. The Fresnel formula for the intensity of refracted light is the following [39]:

$$I_d = \frac{1}{2}\,I_o\,\frac{\sin 2\varphi\,\sin 2\psi}{\sin^2(\varphi+\psi)}\left[1 + \frac{1}{\cos^2(\varphi-\psi)}\right]$$

Here I_o is the incident ray intensity; I_d is the intensity of the refracted ray; φ is the angle of incidence; ψ is the angle of refraction.

Investigation of this formula shows that the energy of the refracted ray is larger, the smaller the angle of incidence.

Hence, the parts of the hot tube close to the faceplates of the light-conductor send very little energy into the quartz because the incident angle of the rays is very large in this case. The rays, emanating from the disc and from the surface of the hot tube at a large distance from the end of the light conductor are incident on the endplate at a small angle, consequently, their effect on the photo-conductor is great. They emanate from elements having a higher temperature under high pressure than the vicinity of the endplate of the light conductor and the thermocouple junction. This means that the FEP will indicate a higher temperature under these conditions than will the thermocouple, as table 6 illustrates.

Certainly, such rays must traverse a considerable path in a compressed gas and, therefore, must experience more or less intense scattering. It is evident that such scattering is not so large for the nitrogen in this apparatus that the measurable radiation is strongly attenuated.

V. Actual temperature measurement

It is evident that the temperature can be measured by radiation under pressure only if the emanating rays do not pass through a medium for which the density varies under pressure depending on the temperature (more exactly, for which the density will vary to a very slight degree depending on the aforementioned parameters) and if the radiator has the actual temperature of the medium. This means the radiator must be at the minimum distance from the end of the light conductor. This would be attained as follows. A steel hood, very close to the endplate (see fig. 4) was slipped onto the end of the quartz rod which was in the furnace. The hood was first annealed at 850° C so that its blackness coefficient could attain a constant value. The hood was 6 mm high, its side walls were 0.2 mm thick and its bottom, 0.4 mm . Such a method completely eliminates the working medium in the path of the measurable radiation, meaning its quantity will depend only on the temperature. Moreover, this method is universal with respect to the optical properties of the medium. None of the absorption bands in the spectrum of the substance used as the working medium has any influence inasmuch as the medium is excluded. Consequently, such a pyrometer can operate in any substances, liquid or gaseous. Since certain investigators have noticed the torsion of the window under the action of high pressure [40,41], which naturally can distort our results, a check of such a phenomenon was made. The obturator carrying the high-pressure window (see 9, fig. 2) was replaced by another. The first had an 8 mm diameter of the inner orifice and the second had a 4 mm diameter. Hence, the area of the window subjected to the bending was diminished 4 times for the second obturator and the torsion of the window would have so much less a degree. Comparable experiments, made on the two obturators under atmospheric and high pressures, did not show any variation in the radiation intensity. This means there is no torsion of the window and no errors occur from such a phenomenon. The experiments conducted with a light-conductor provided with a hood gave the results shown in tables 7 - 9 .

Table 7. P = 1000 $^{kg}/_{cm^2}$. Medium - nitrogen

Temperature, by thermocouple	400^o	450^o	500^o	550^o
Temperature by FEP	390^o	437^o	484^o	534^o

As is seen, the FEP indicates a lower temperature than the thermocouple, where the difference increases as the absolute temperature increases.

Table 8. T = 400^o C, by thermocouple. Medium - Nitrogen

P, $^{kg}/_{cm^2}$	1	120	300	600	900	1500
Temperature by FEP	400^o	388^o	381^o	388^o	392^o	394^o

As is seen, a small divergence occurs between the thermocouple and the FEP at a 300 $^{kg}/_{cm^2}$ pressure. The readings of the thermocouple and the FEP start to converge as the pressure is increased further.

Table 9. T = 450^o , by thermocouple. Medium - Argon

P, $^{kg}/_{cm^2}$	1	120	300	600	1000
Temperature by FEP	450^o	435^o	428^o	438^o	444^o

Hence, the divergences of the thermocouple and FEP readings in argon have the same character as in nitrogen. These divergences are apparently due to a temperature difference arising between the thermocouple in the wall of the heated tube and the hood suspended at its center, under high pressure. The non-isothermy decreases at pressures above 300 $^{kg}/_{cm^2}$ because of the increase in the heat transmission.

After these experiments, similar ones were made with hydrogen, an aggressive gas for the thermocouple material. They showed that a chromel-alumel thermocouple is completely unsuited to measure temperatures in hydrogen at high pressure; its readings are completely distorted.

Conclusions

1. Any optical investigations at high pressure and high temperature (spectral, temperature, visual, etc.) should be made so that the whole path of the rays from the high temperature zone to their issuance from the high pressure region would travel over an isotropic solid body where density inhomogeneities are excluded completely.

2. The photoelectric pyrometer of the abovementioned construction is a contactless and inertialess instrument to measure the temperature at high pressure for any media which are not aggressive with respect to the material of the light-conductor.

3. As a result of the investigation, it can be concluded that works in which the temperature was measured at high pressure by an optical method should be referred to with care because of the possible errors due to the inhomogeneities of the medium.

The authors thank A. A. Khrushchev, N. S. Khlebnikov and N. N. Sobolev for valuable comments and assistance during the experiments and for aid in selecting a photocell with the requisite properties. The installation was assembled by mechanic V. IA. Volodin whom the authors thank for an irreproachable job.

February 27, 1956

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